

# **Acoustic Scattering Classification of Zooplankton and Microstructure**

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## **LONG-TERM GOALS**

To understand the acoustic reverberation properties of zooplankton and microstructure. This new understanding will lead to improved capability in 1) predicting sonar performance and 2) use of sonars in the mapping of the zooplankton and microstructure.

## **OBJECTIVES**

To understand the physics of the scattering by naturally occurring (complex) bodies or processes. Realistic acoustic scattering models of zooplankton and microstructure will be developed and applied to high-frequency acoustic surveys.

## **APPROACH**

The research program has been a combination of theoretical analysis, numerical simulations, and experimentation in the laboratory and local waters at WHOI. The acoustic scattering theories are approximate and have included various ray, volume integration, and modal-series-based solutions. An acoustic pulse-echo laboratory is used to collect backscatter data with animals over a wide range of acoustic frequencies (24 kHz - 1 MHz) and all angles of orientation (0 to 360 degrees in 1-degree steps). The system is also used in a more limited capacity to measure scattering by microstructure. A high performance towed platform (BIOMAPER-II) is used to simultaneously collect acoustic backscatter data (transducers at five frequencies (43 kHz to 1 MHz) looking up and down), video data, and environmental data (temperature, etc.). Tim Stanton has led the laboratory measurements and development and application of scattering modeling while Peter Wiebe leads the field surveys and interpretation. Dezhang Chu has also played a key role in the laboratory and modeling work while Joe Warren and Andone Lavery have played key roles in the surveys and classification.

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## **WORK COMPLETED**

A number of major tasks were completed this year involving various parallel efforts focused principally on a scattering-model-based classification of our high-frequency acoustics survey data.

1) **PUBLICATIONS.** In FY01, three journal articles appeared in print, one doctoral thesis was completed and archived, three previously submitted papers have been accepted and/or are now in press, one new paper was submitted and accepted, and two more are in advanced stages of preparation. We also continued to make significant progress toward putting into final form the book that was accepted in an earlier year. **AWARD:** A former student funded by this project, Dan DiPerna, received the “Ruth and Paul Fye Award for Excellence for the Best Paper” by the Woods Hole Oceanographic Institution.

2) **ANALYSIS OF BIOMAPER-II CRUISE DATA.** The last two scientific cruises of a five-cruise series using the newly developed towed instrument platform BIOMAPER-II were completed in the previous year in the Gulf of Maine. Much of our effort this year involved processing the data from cruises #4 and #5. This analysis included integrating acoustic scattering data with samples of organisms (from MOCNESS net tows and the video plankton recorder) and environmental data (from cast and towed CTD's). The integration has involved statistical comparison of the different types of data (through correlations) and a scattering-model based analysis. Also, samples from the MOCNESS net tows were analyzed. This analysis has provided estimates of the proportions with which the scattering is due to each of the various anatomical groups of animals and microstructure. Inferences are being made from the acoustic data to parameterize the animals and microstructure field.

## **RESULTS**

1) **DISCRIMINATING BETWEEN SCATTERING BY ZOOPLANKTON AND MICROSTRUCTURE.** We have observed variability both with respect to depth and region in what is the dominant source of acoustic scattering in the water column. In one region in which an internal wave was observed, the microstructure appears to dominate the scattering in the upper water column--that is, in the near-surface mixing zone. In the lower portion of the water column, the zooplankton appear to be the most significant source of scattering (Figure 1). In another region, also where an internal wave was present, the zooplankton appeared to have dominated the scattering throughout the water column.

2) **QUANTIFYING SCATTERING BY ZOOPLANKTON AND MICROSTRUCTURE.** After determining the most significant sources of scattering in the first region mentioned above, we have produced 2-D maps of zooplankton size, numerical density of the zooplankton, and dissipation rate of the turbulent kinetic energy. The maps regarding the zooplankton involve the species (euphausiid) that dominated the echoes (Figure 1). These maps quantify the spatial variability of the zooplankton and microstructure, as well as their interrelationship.

3) **OBSERVATIONS OF SIPHONULAE.** As part of this investigation, we have been observing concentrations of siphonulae, a larval form of the gas-bearing zooplankton siphonophore. The observations were made possible through use of the video plankton recorder mounted on the BIOMAPER-II system as it was tow-yoed throughout the water column. The concentrations were much higher than those observed using the conventional net system (the animals are very fragile and are usually destroyed by nets). Our calculations show that the gas-bearing animals have resonance

frequencies in the low 10's of kilohertz region and were significant and possibly even dominant sources of scattering in some of the scattering layers, especially at the lower frequencies of BIOMAPER-II.

## **IMPACT/APPLICATIONS**

The impact and applications of these results are significant: 1) Traditionally, and with few exceptions, high frequency acoustic scattering from the water column has been attributed entirely to the presence of marine life. Thus, when measurements of acoustic scattering are made, the results were automatically converted into some measure of biomass of animals. Since our results show that there are conditions under which the source of scattering could be a physical process, those types of analyses could grossly overestimate the presence of marine life. As a result of this analysis, we are now producing maps of meaningful biological (size and numerical density) and physical (dissipation rate of turbulent kinetic energy) parameters. 2) As part of these studies, we have observed concentrations of the larval form of an important zooplankton (siphonulae) that would have otherwise gone undetected through conventional net sampling techniques. These animals, initially observed by us through the video plankton recorder that is mounted on BIOMAPER-II, were also determined to be significant sources of scattering by sound.

## **TRANSITIONS**

1) We have met with NUWC/Newport personnel this year as part of our ongoing interest in transitioning the results of this work to Navy systems. A key aspect of the problem is our knowledge of the spatial and temporal variability of the biological sources of sound scattering. 2) Numerous laboratories outside WHOI have been applying the models developed in this project (or derivatives of the models) to assess marine life. For example, in this past year, papers have been submitted or published by scientists at Scripps Institution of Oceanography and Texas A&M using our models. 3) Some of our acoustic scattering models have been used in the past by NUWC/Newport in sonar performance predictions in their development of the standoff system, which remains operational.

## **RELATED PROJECTS**

We have recently applied our laboratory, signal processing, and scattering methods to two other projects: 1) measurements and modeling of acoustic scattering by fish (funded by another grant by ONR and NOAA). 2) measurements of biotechnical properties (sound speed and mass density) of various zooplankton (funded through a private grant).

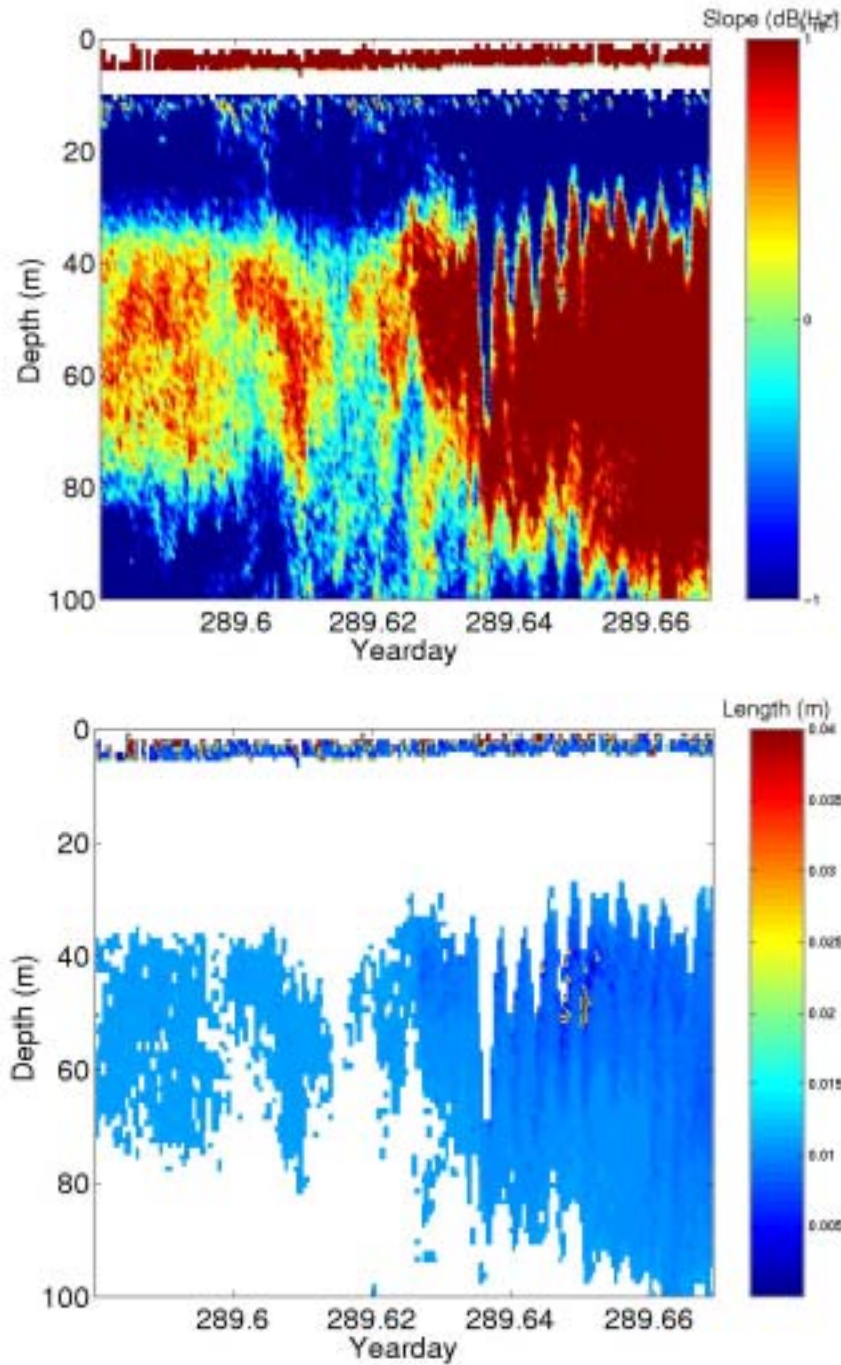
## **PUBLICATIONS**

Lavery, A.C., T.K. Stanton, D.E. McGehee, and D. Chu. "Three dimensional modeling of acoustic backscattering from fluid-like zooplankton," accepted to *J. Acoust. Soc. Am.*

Foote, K.G. and T.K. Stanton. Observing Aquatic Organisms by Sound and Light, accepted to Springer-Verlag.

Pershing, A.J., P.H. Wiebe, J.P. Manning, and N.J. Copley, 2001. "Evidence of vertical circulation cells in the well-mixed area of Georges Bank and their biological implications," *Deep-Sea Res. II*, 48: 283-310.

- Stanton, T.K. and D. Chu, 2000. "Review and recommendations for modeling of acoustic scattering by fluid-like elongated zooplankton: Euphausiids and copepods," *ICES J. Mar. Sci.* 57(4): 793-807.
- Stanton, T.K., D. Chu, L.V. Martin Traykovski, D.B. Reeder, J.D. Warren, and P.H. Wiebe, 2001. "Broadband acoustic classification of individual zooplankton and fish: A review of recent work," in Proceedings of the Institute of Acoustics Conference on Acoustical Oceanography (April), 181-188.
- Wiebe, P.H. and M.C. Benfield. "From the Hensen Net toward 4D biological oceanography," accepted to Progress in Oceanography.
- Wiebe, P.H., T.K. Stanton, C.H. Greene, M.C. Benfield, H.M. Sosik, T. Austin, J.D. Warren, and T. Hammar. "Biomaper-II: An integrated instrument platform for coupled biological and physical measurements in coastal and oceanic regimes," accepted to *IEEE J. Ocean. Eng.*
- Warren, J.D., 2001. "Estimating Gulf of Maine zooplankton distributions using multiple frequency acoustic, video and environmental data," Ph.D. Thesis, MIT/WHOI Joint Program, 219 pp.
- Warren, J.D., T.K. Stanton, M.C. Benfield, P.H. Wiebe, D. Chu, and M. Sutor, 2001. "*In situ* measurements of acoustic target strengths of siphonophores, a gas-bearing zooplankter," *ICES J. Mar. Sci.* 58: 740-749.
- Warren, J.D., T.K. Stanton, D.E. McGehee, and D. Chu, In press. "Influence of animal behavior on acoustic estimates of zooplankton properties," *IEEE J. Ocean Eng.*



**Figure 1.** Sources of acoustic scattering and quantification of their parameters in an internal wave field in Wilkinson Basin, Gulf of Maine. Analysis based on multi-frequency acoustic echo data measured with BIOMAPER-II. **UPPER PANEL:** Color contour of slope of acoustic spectra. Blue color (negative spectral slope) indicates that microstructure is dominant scatterer. Red and yellow colors (positive spectral slope) indicate that zooplankton (non-gas-bearing) are the dominant scatterer. **LOWER PANEL:** Color contour of length of zooplankton (euphausiid) that dominated the scattering. Most of the animals are shown to have nearly the same size of 1.5 cm. Since the ship traveled at a constant speed, the horizontal axis corresponds directly to distance along the transect.